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# MODULATION TECHNIQUES FOR POWER AND SPECTRALLY EFFICIENT SATCOM SYSTEMS

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## ABSTRACT

Research on modulation/demodulation (modem) techniques which leads to improved power and spectral efficient digital satellite communications systems is proposed. A new family of digital modems, which enable satellite earth station and satellite transponder operation with fully saturated high power amplifiers (HPA) in an adjacent channel environment, having an optimized  $P(e) = f(E_b/N_o)$  performance will be introduced and analyzed.

We propose the study of Superposed-Quadrature-Amplitude-Modulated (SQAM) systems which have offset and/or coincident transition crosscorrelated and pulse overlapped baseband signal processors. We will introduce and optimize the performance of a new generation of  $\pi/4$ -shift SQAM linear modulation techniques for fully saturated power amplifier and spectrally efficient SATCOM system applications. It is expected that  $\pi/4$ -shift SQAM and  $\pi/4$ -shift bandlimited QPSK systems will have reduced envelope fluctuations and lead to reduced spectral spreading. A new class of linear and nonlinear phase transmit and receive intersymbol-interference (ISI) free filters combined with reduced overshoot power baseband signal processors is also expected to lead to improved efficiency SQAM digital satellite transmission systems.

The proposed new generation of SQAM modulated signals is suitable for coherent as well as for differential demodulation. Differential demodulators have a faster synchronization time than their coherent counterparts. The performance of our proposed modems will be compared with the performance of continuous phase modulation (CPM) and trellis coded satellite modems.

Following the proposed theoretical investigations and computer simulations, hardware prototypes will be built and tested.

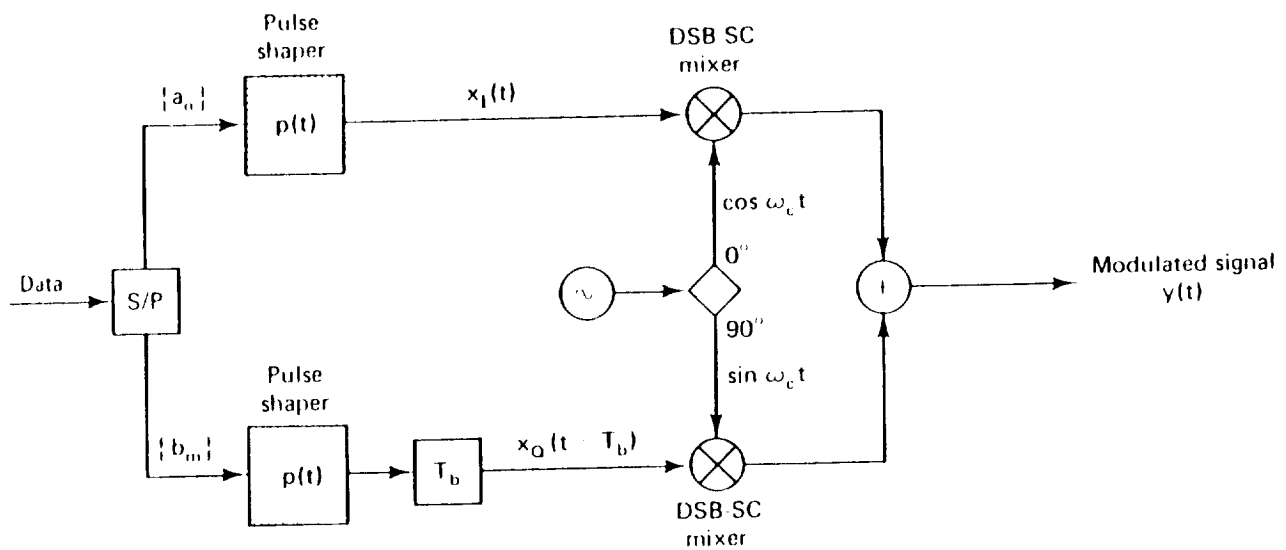
(\*) Work funded under Grant No. NAG 3 1007; NASA Technical Officer: J. M. Budinger

## OBJECTIVES OF PROPOSED RESEARCH

Our goal is to improve the power and spectral efficiency and the network flexibility of new generations of digital satellite and other digital transmission systems. To achieve this goal we propose to undertake the development and analysis of the following closely related research tasks:

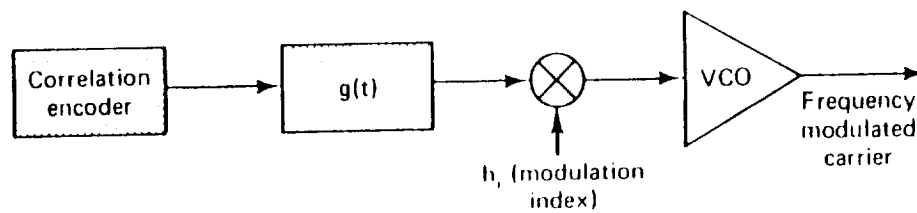
- (a) Introduce and study the performance of a new generation of **Superposed-Quadrature-Amplitude-Modulated (SQAM)** digital satellite communications systems. Research of our crosscorrelated nonlinear-phase ISI free premodulation filters with reduced overshoot power [1] is expected to lead to an increased spectral efficiency of about 50% and to a 2 to 4 dB improved power efficiency in a nonlinearly amplified system. The proposed modem techniques will be optimized in a complex interference environment, including Additive White Gaussian Noise (AWGN), Adjacent Channel Interference (ACI) and Co-Channel Interference (CCI).
- (b) Introduce and optimize  $\pi/4$ -shifted **SQAM** and  $\pi/4$ -shifted QPSK satellite modems operated in nonlinear satellite systems. These bandlimited linearly modulated systems have a reduced envelope fluctuation and reduced spectral spreading.  $\pi/4$ -shift SQAM modulated signals may be **coherently and differentially demodulated** [2].

In order to reduce the size of the antenna and or to enable operation with smaller, lower cost earth station high power amplifiers (HPA), new modulation/demodulation system models will have to take into account high power efficiency requirements. The objective of our research is to develop a new family of digital modems which will enable satellite earth station transmitter operation with fully saturated HPA in a closer spaced adjacent channel environment. Our proposed new system models as well as hardware prototypes are expected to achieve a good performance **without** the requirement of complex (and with present technology frequently impossible) **post HPA filters**. We propose to have a low-power-hard-limiting-amplifier (LPHA) before the final HPA amplifier. LPHA devices can be designed to have a much lower AM to PM conversion than their HPA counterparts.



S/P = serial to parallel converter  
 $T_b$  = bit interval,  $T_b = T_s/2$   
 $T_s$  = symbol interval

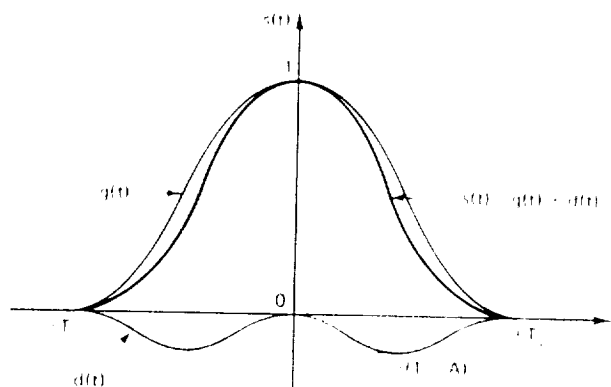
(a)



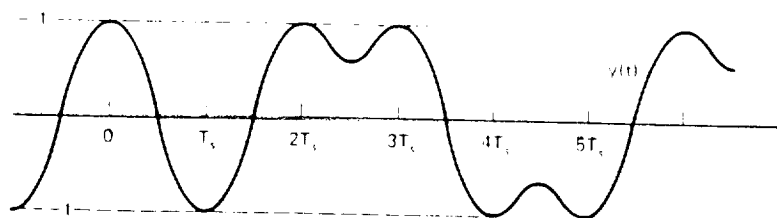
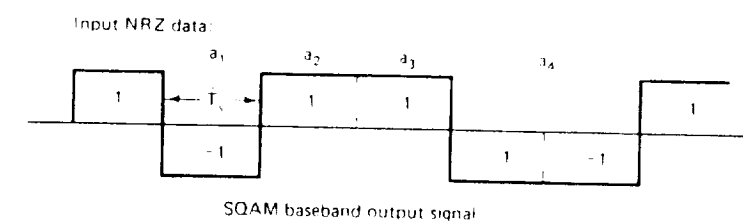
VCO = voltage controlled oscillator

(b)

Figure 1 (a) Block diagram of a quadrature amplitude modulator  
 (b) Block diagram of CPFSK modulator

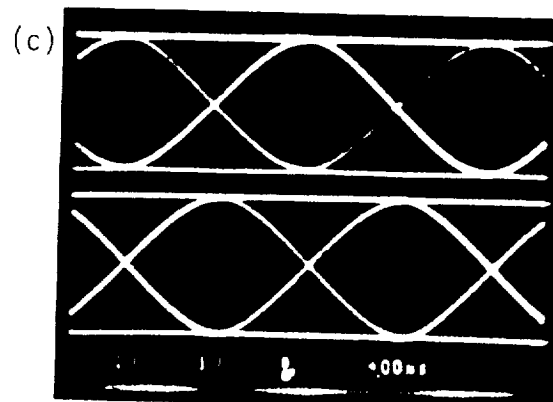
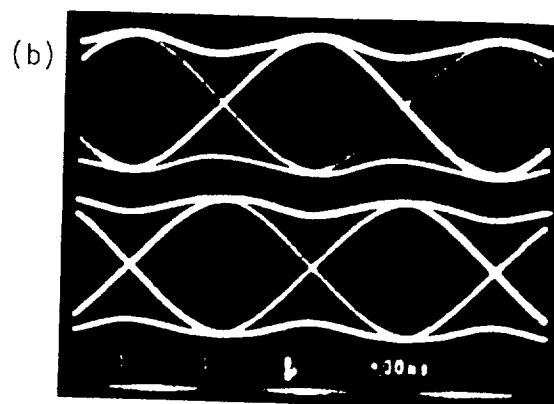
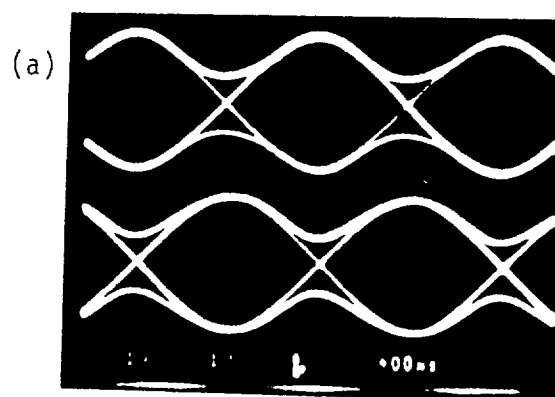


(a) An example of an SQAM double interval pulse  $s(t)$ , which is a superposition of  $q(t)$  and  $d(t)$

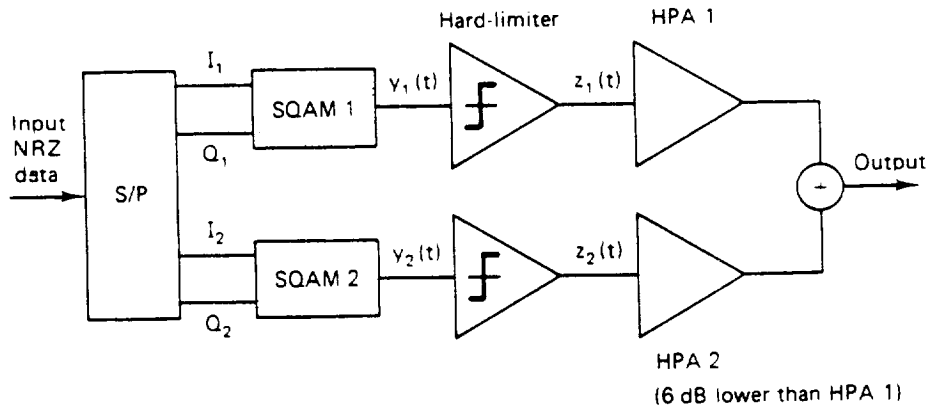


(b) Processed SQAM baseband output

**Figure 2** SQAM baseband signal shaping process using the double-interval pulse overlapping concept. (Note:  $T_s = 2T_b$  is the symbol interval, where  $T_b$  is the bit interval)



**Figure 3** Experimental measured eye patterns (I- and Q-channel) of SQAM baseband signals of a 128-kb/s modem in a linear channel. (a)  $A = 0.7$ . (b)  $A = 0.85$ . (c)  $A = 1.0$ . These eye patterns were measured at the transmitter, prior to modulation (Vertical: 1 V/division; horizontal: 4  $\mu$ s/division.)



\*\*HPA 1 and HPA 2 are operated in a saturation mode

Figure 4: Block diagram of 16-SQAM modulator

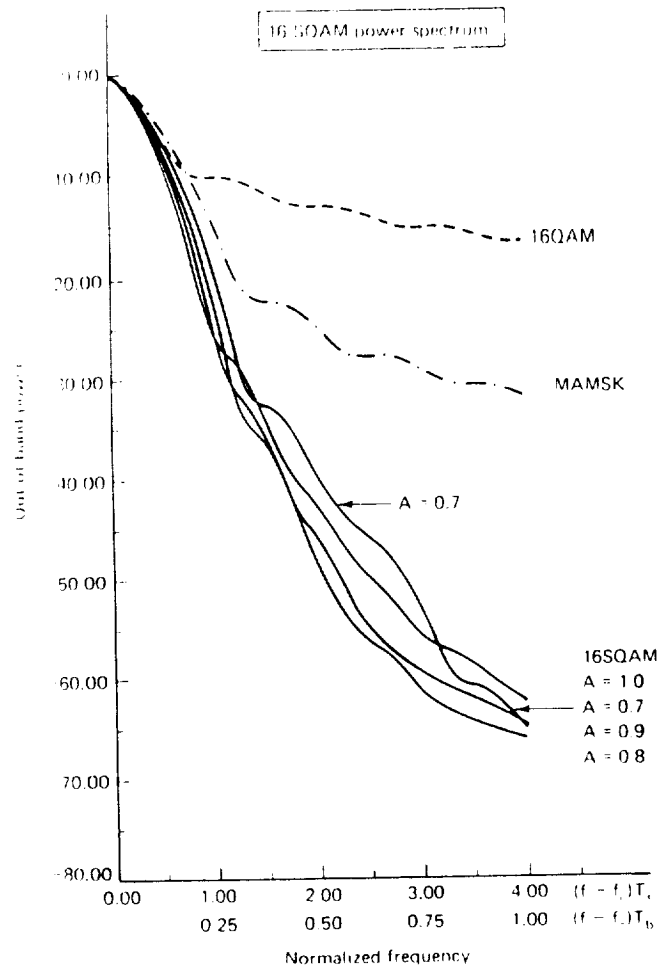


Figure 5: Out-of-band-to-total-power ratios of 16-SQAM, MAMSK and 16-QAM signals in a nonlinear (hard-limited) channel

# NON-LINEAR PHASE FILTERS FOR DIGITAL SATCOM SYSTEMS

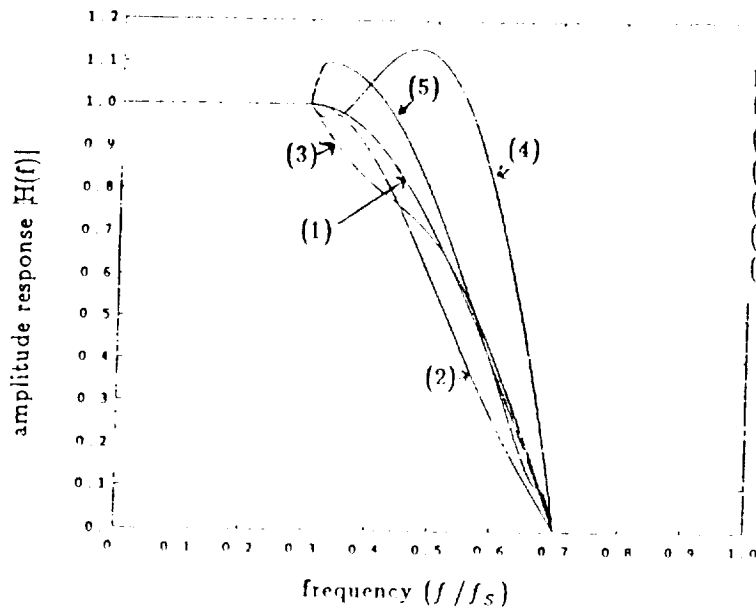


Figure 6 Amplitude responses of several nonlinear phase ISI-free filters using the following functions from Table I III. ( $\alpha=0.4$  is assumed.)

- (1)  $G_0(f), U_2(f), V_1(f)$
- (2)  $G_0(f), U_2(f), V_2(f)$  ( $b=0.3$ )
- (3)  $G_0(f), U_1(f)$  ( $k=1$ ),  $V_4(f)$  ( $\alpha=0.3, b=0.5$ )
- (4)  $G_0(f), U_1(f)$  ( $k=1$ ),  $V_3(f)$  ( $\alpha=4$ )
- (5)  $G_3(f)$  ( $\beta=0.35, g=1.1$ ),  $U_2(f), V_1(f)$

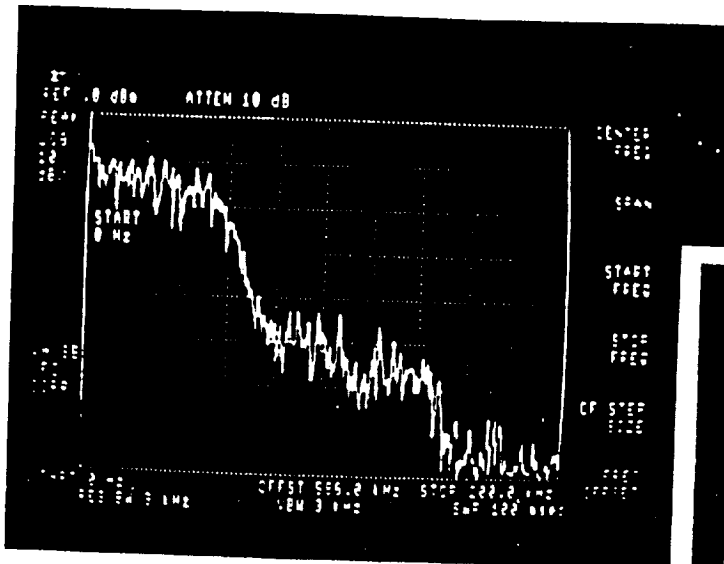


Figure 7 Power Spectral Density of the PRBS signals filtered by the filter in Figure 6  
Bit rate = 100kb/s is used which corresponds to clock rate of 400kHz.

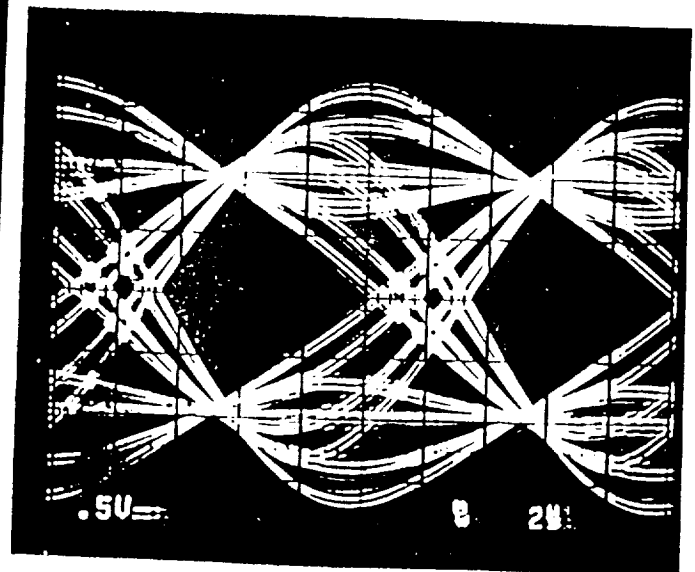


Figure 8 Eye-diagram of the PRBS filtered by the filter in Figure 6. Bit rate = 100kb/s is used.  
Without noise

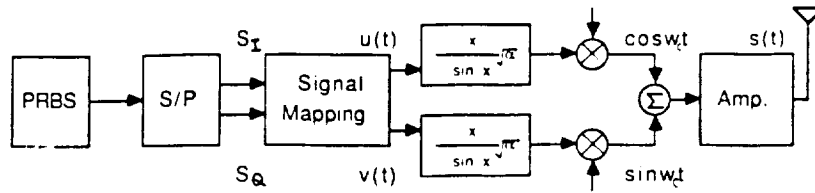


Figure 9: Block diagram of the transmitter of the  $\pi/4$ -QPSK modem systems [2]

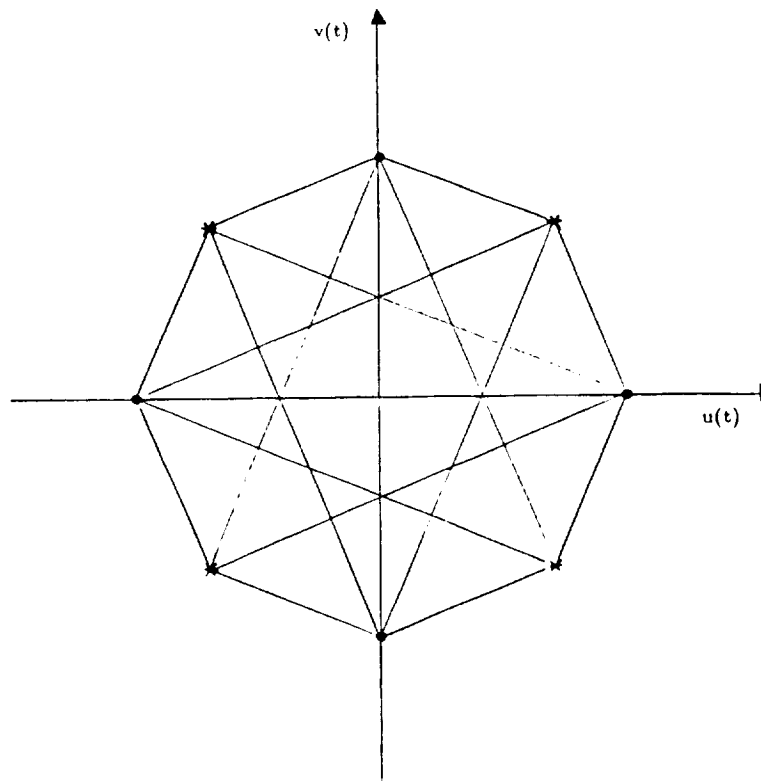


Figure 10 Possible phase states of the  $\pi/4$  QPSK modulated carrier at sampling instants. The connections between two states indicate the possible phase transition.

$$* T = 2nT_s$$

$$. t = (2n+1)T_s$$

$T_s$  : symbol duration

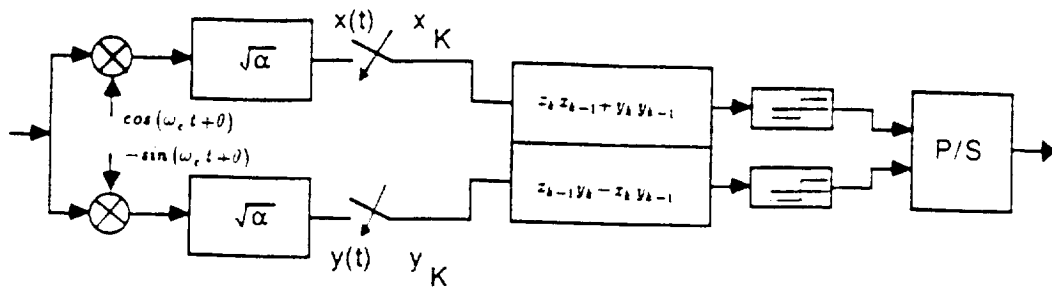


Figure 11: Block diagram of the baseband differential detector.

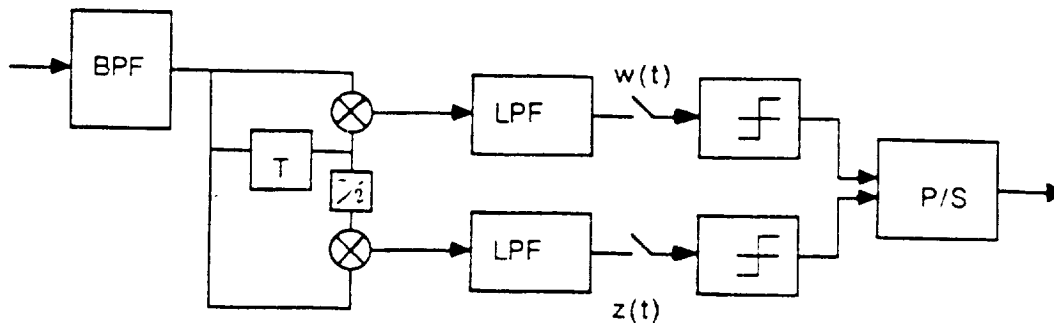


Figure 12: Block diagram of the IF band differential detector employing delay line and mixers.

BPF is assumed to have square-root raised-cosine roll-off.

LPF is assumed to be ideal brick-wall with  $BW = 2(1+\alpha)f_N$

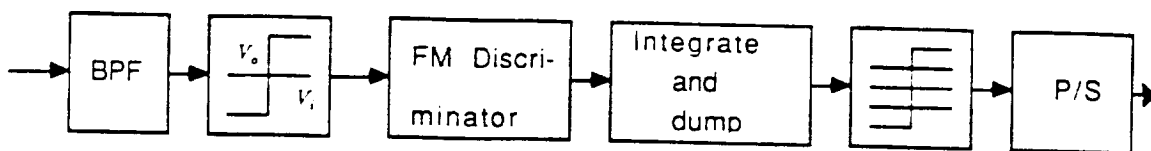


Figure 13: Block diagram of the FM-discriminator.

Module  $2\pi$  is used in the threshold detector [2].



## REFERENCES FOR THIS PRESENTATION

**(Limit to two references)**

- 1) K. Feher, Ed: "Advanced Digital Communications Systems and Signal Processing Techniques," Prentice-Hall, Englewood Cliffs, NJ 07632, 1987.
- 2) C. L. Liu, K. Feher: "Noncoherent Detection of  $\pi/4$ -QPSK Systems in a CCI-AWGN Combined Interference Environment," Proc. of the IEEE-VTC-89, April 29-May 3, 1989 (pp. 83-94), San Francisco, CA, May 1989.

